

Magnetic force microscopy images of magnetic garnet with thin-film magnetic tip.*

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Abstract

We present magnetic force microscopy images of YGdTmGa/YSmTmGa magnetic garnet, using a thin Fe film deposited on Si₃N₅ tips. We have found correlations between the topography and the magnetic domain structure. We have observed the domain wall contrast with a iron thin-film tip. We report on domain wall imaging of garnet with magnetic force microscopy.

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INTRODUCTION.

In this letter we present a different approach for the study of magnetic garnets with magnetic force microscopy (MFM). Low coercivity magnetic materials are especially difficult to study by means of MFM. The magnetic tip used to sense the stray field of the magnetic sample may, due to its own fringing field, disturb the sample domain structure.¹ Recently, tunneling-stabilized magnetic force microscopy (TSMFM) has been used to image domains in very low coercivity magnetic garnet, $H_c=40$ A/m (0.5 Oe).² Briefly, TSMFM is performed by using a scanning tunneling microscope (STM) with a flexible magnetic tip.³⁻⁵ TSMFM images are combinations of surface topography and the magnetic forces on the tip.

It is important to have corresponding topographic and magnetic images of the same area. This gives us the opportunity to study correlations between the morphology of the surface and the magnetic domain structure. We present high resolution magnetic force microscopy images of magnetic garnet with their corresponding topographic images. We have succeeded in observing the undisturbed magnetic domain structure. Furthermore, by choosing the appropriate coatings we have obtained high resolution images of the domain walls in garnet films.

RESULTS.

We have used a magnetic force microscope based on the atomic force microscope (AFM) described by Alexander et al.,⁶ and which uses a laser-photodiode detection scheme. This MFM relies directly on force measurement as described by

Giles et al.⁷ The sample is rastered with a piezoelectric tube scanner. A cantilever with an integrated tip is placed at 15° relative to the sample surface. First, the tip is brought into contact with the sample's surface and performs one scan line to determine the sample's topography. After the topography of this scan line is stored, the tip is raised above the sample surface and scanned again along the path predetermined by the previous scan. The tip-sample separation of that scan is nominally constant. Small deflections of the cantilever due to magnetic interaction between the sample and the magnetic tip are then measured as a function of position. Such a procedure provides both the topography and the magnetic force images of the same area.

We have used magnetic thin films deposited on commercially available Si_3N_5 tips as magnetic sensors. Similar tips have been successfully used before in TSMFM to study hard magnetic samples.⁵ All of the data presented here have been taken with cantilevers having a spring constant of $k=0.06$ N/m.

The samples we studied were epitaxially grown YGdTmGa/YSmTmGa garnet films on $\text{Gd}_3\text{Ga}_5\text{O}_{12}$ substrates.² The garnet has a saturation magnetization $4\pi M=35.7$ kA/m (448 G) and a coercivity 40 A/m (0.5 Oe).

Figure 1 shows data obtained with a tip that was coated with 10 nm of Fe and 10 nm of Ni and then was magnetized in a field of 10^5 A/m. The tip-sample separation was 250 nm for this image. In Fig. 1(b) wide dark and bright stripes represent domains with opposite magnetization. The periodicity of these stripes correlates very well with the periodicity of the garnet domain structure, which is known from Faraday

data.² The tip is magnetized perpendicular to the sample surface and is attracted by domains with the same magnetization direction, giving the dark contrast on the MFM image. When the tip is repelled off the surface, the bright contrast appears. We have not observed any evidence of changes in the sample domain structure while the sample was scanned. The topography image (Fig. 1(a)) reveals some scratches running diagonally from upper left to lower right. We have marked these with arrows. These scratches have depths varying from 4 to 8 nm. The scratches either originate in the substrate or were formed in the film during the liquid phase epitaxy. The configuration of the magnetic domain structure appears to be influenced by the surface topography. Domains are parallel to these scratches, whereas in the area between the scratches the domains turn almost 90°. We emphasize that the capability of simultaneously taking topographic and magnetic images with the AFM allows us to reveal this kind of dependence on this scale.

In order to image the domain walls in the garnet the MFM tip had to be very sensitive. We tested several different types of thin-film tips. Very good results were obtained with a 10 nm Fe thin-film tip, not magnetized before to the experiment.

Figure 2 shows the data obtained with that thin-film tip. The nominal tip-sample separation was 20 nm for this image. In this case, the narrow bright lines represent the domain wall contrast. Figure 3 shows a $4\text{ }\mu\text{m} \times 4\text{ }\mu\text{m}$ scan of the domain walls shown in Fig. 2. The profile line across the domain walls is shown below the image indicating a 13 nm tip displacement. The associated force is 7.8×10^{-10} N. We have included Fig. 4 to explain why domain walls are visible as bright lines. The curve (a)

represents the magnetic force curve obtained with magnetically hard tip when the thickness of the sample is comparable with the domain width.⁸ The curve (b) shows the case when the tip is magnetically soft. In this case the tip magnetization follows the sample stray field. Then the tip is always attracted to the sample giving the same signal from all domains. Thus the domain wall appears as high contrast. The experimentally observed domain wall contrast (note the cross-section in Fig. 3) is similar to the model contrast from Fig. 4 (curve b), with sharper indicated domain walls and the rounded domains. Figure 5 presents the $2\ \mu\text{m} \times 2\ \mu\text{m}$ image of the single domain wall observed with tip-sample separation of 20 nm. The domain wall is symmetrical. The width of the domain wall measured at the half of its height is about 355 nm and does not change substantially with tip-sample separation from 40 nm to 15 nm. We think that the further decrease of the domain wall width is possible only with a different shape of the substrate tip.

Furthermore, although the tip emits a fringing field, it does not affect the domain wall. We have looked at images, scanned from left to right and vice versa, and we have observed no domain wall bending due to the tip's field.

In summary, using this MFM technique we have imaged domains and domain walls on low coercivity YGdTmGa/YSmTmGa magnetic garnet. The Fe thin-film tips appeared very sensitive giving contrast from domain walls. Observed domain walls were symmetrical. Furthermore, the sample domain structure was not affected by presence of this kind of tip.

The dependence of magnetic domain structure on surface topography has been

observed for magnetic garnet. The comparison of topography to magnetic structure is important for magnetic thin-film devices presently being considered in vertical Bloch line (VBL) nonvolatile data storage circuits.⁹

We think, with further work on grooved samples, that we will be able to see Bloch lines in the domain walls of garnet films.

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FIGURE CAPTIONS

1(a). Topography of epitaxially grown YGdTmGa/YSmTmGa garnet. The arrows point to shallow scratches which affect domain structure (see Fig.1(b)).

1(b). Magnetic domain structure of the garnet obtained with a magnetized Fe-Ni double layer thin film tip.

2. Domain wall contrast obtained with the 10 nm Fe thin-film tip. Bright lines represent domain wall contrast. The tip-sample separation was 20 nm in this case.

3. The smaller scan of the domain walls. The cross-section line was taken across the walls as marked on the figure. The tip-sample separation was 20 nm.

4. Curve (a) represents a typical magnetic force curve obtained with magnetically hard tip. Curve (b) shows the magnetic force curve obtained with magnetically soft tip.

5. MFM image of the single domain wall obtained with 10 nm Fe coating. The cross-section line was taken across the wall as marked on the figure. The width of the domain wall observed at the half of its height was 355 nm. There were 512 experimental points in single scan line.

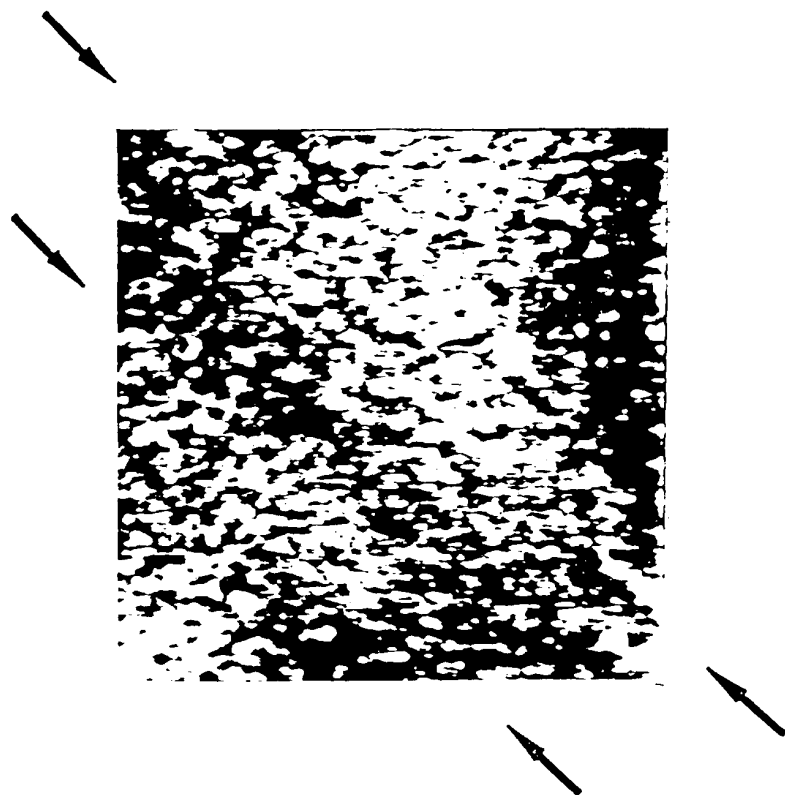


Fig. 1(a)

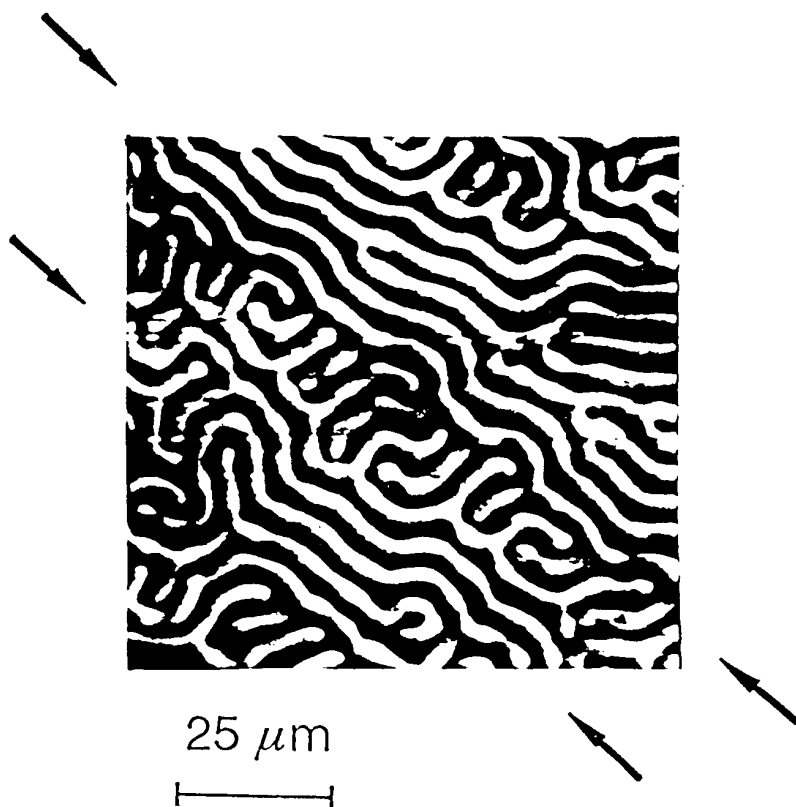


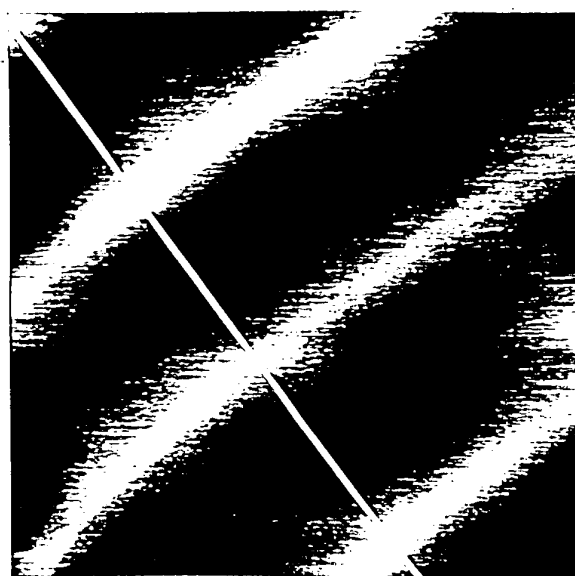
Fig. 1(b)

Fig.2



5 μm
└────────┘

Fig. 3



1 μm

10 nm I



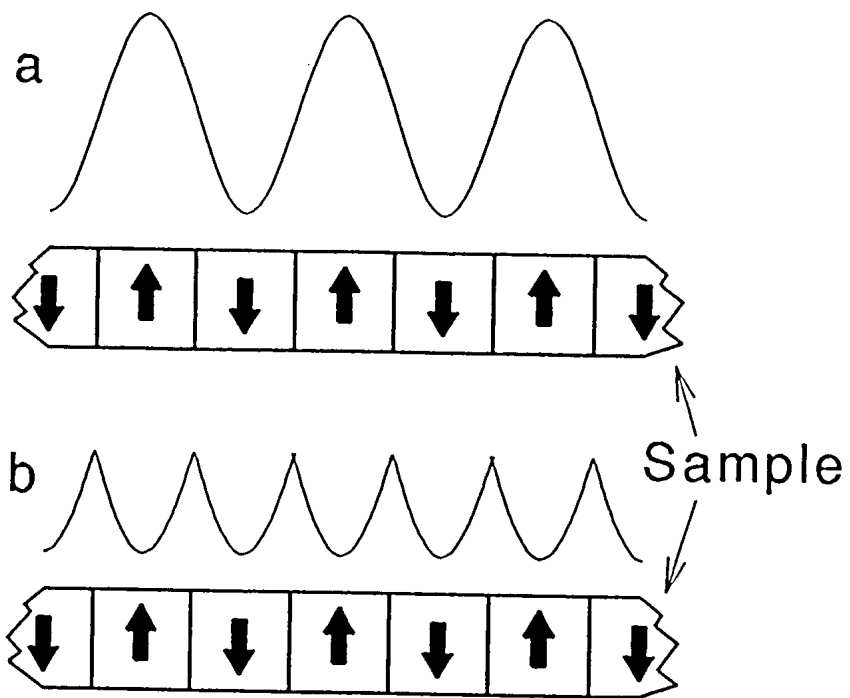
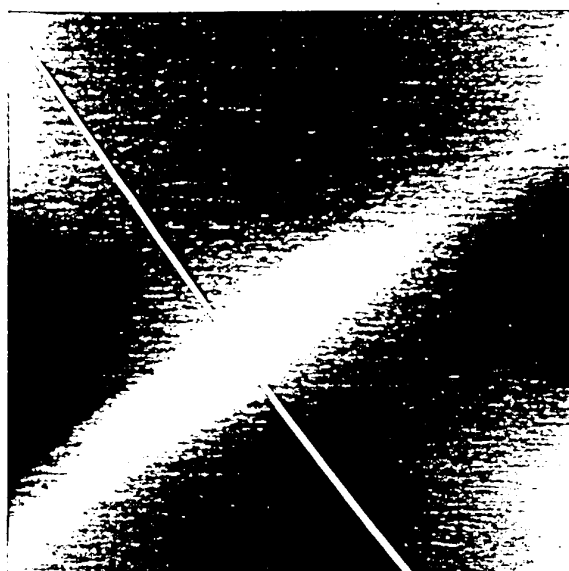
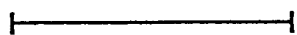


Fig 4.

Fig. 5



1 μm



10 nm I

